Smugglers and Border Guards: the Geo* Project at RPI

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A Terrain Representation

Not produced by a sponsor of this conference.
Smugglers and Border Guards: the Geo* Project at RPI

- **ODETLAP** – Very compact terrain representation,
- **Border guards** - Multiple observer siting to maximize joint viewshed,
- **Smugglers** - Path planning to avoid viewsheds
**ODETLAP Process**

- **400x400 matrix of elevations**
- **contour lines**
- **any user-suppied points, even inconsistent**

**ODETLAP point selection**

**ODETLAP terrain reconstruction**

**400x400 matrix of elevations**

*First ODETLAP mention: my 1998 Spatial Data Handling Symposium (Vancouver) talk.*

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**ODETLAP Point Selection**

**Several options:**

- Incremental TIN to find most important points, then greedy insertion of worst points *(Allows progressive transmission)*
- Regular grid of points (more points, but compress better) *(More compact)*
- Stream and ridgeline points *(Preliminary)*
**Incremental Triangulated Irregular Network (TIN)**

- Can process $10^8$ points on a laptop.
- Works in memory w/o needing to page data from disk.
- Inserts points incrementally, in order of importance.
- Can progressively transmit terrain.
- Identifies ridge lines automatically.

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**Coding the Points to Reduce Space**

- As important as point selection.
- Code $(x, y)$ separately from $z$.
- If $(x, y)$ a regular grid: give its resolution
- Else: run-length encode the bitmap.
  - $0100000011000010001 \rightarrow 16043$
  - Only about 1000 of 160,000 bits are 1.
- Only 20% over info theoretic min:
  - $\lg(\text{choose}(160000, 1000)) = 8754 \text{ bits}$
- $Z$: delta code, then $bzip2$.
  - 100 125 90 90 100 -> 100 25 -35 0 10

- Zhongyi Xie
**Traveling Salesman Path**

- *Hypothesis*: nearby points often have nearby Z, which delta code better
- Find a traveling salesman path through the selected points.
- Put the Z in that order and code them.
- (X,Y) coding is not affected.
- *Status*: have some preliminary results.

  - Barb Cutler

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**Info theoretic min for (x,y)**

- Assume that 1000 of 400x400 bits are 1, rest are 0.
- That’s why we separate (x,y) from (z).
**ODETLAP Reconstruction - 1**

- Extension of classical Laplacian partial differential equation used to solve heat flow etc.
- Now possible with new numerical computation techniques on large sparse overdetermined systems of linear equations.
- Adds capabilities to the classical PDE:
  - Local maxima inference
  - Inconsistent data conflation

**ODETLAP Reconstruction - 2**

- Solve overdetermined variant of Laplacian PDE.
  - *Known pts:* \( z_{ij} = h_{ij} \)
  - *All pts:* \( 4z_{ij} = z_{i-1j} + z_{i+1j} + z_{ij-1} + z_{ij+1} \)
- Easily processes 400x400 arrays of elevation posts in Matlab (160,000 unknowns).
Four Matlab Interpolation Techniques on Nested Square Contours

This difficult example was chosen to illustrate all these methods' limitations.

ODETLAP on Nested Squares

Surface now looks much better. Can tradeoff accuracy vs smoothness.
Terrain Test Data

Extracted from level 2 DEMs

Elevation range

TIN + Greedy ODETLAP Results

<table>
<thead>
<tr>
<th>Data</th>
<th>Size, bytes</th>
<th>Compression ratio</th>
<th>RMS Elev Error, m</th>
<th>RMS Slope Error, deg</th>
</tr>
</thead>
<tbody>
<tr>
<td>hill1</td>
<td>1880</td>
<td>170:1</td>
<td>2.83</td>
<td>3.53</td>
</tr>
<tr>
<td>hill2</td>
<td>1962</td>
<td>163:1</td>
<td>4.06</td>
<td>8.06</td>
</tr>
<tr>
<td>hill3</td>
<td>1739</td>
<td>184:1</td>
<td>1.66</td>
<td>1.65</td>
</tr>
<tr>
<td>mtn1</td>
<td>1979</td>
<td>162:1</td>
<td>3.77</td>
<td>14.0</td>
</tr>
<tr>
<td>mtn2</td>
<td>2006</td>
<td>160:1</td>
<td>4.31</td>
<td>14.1</td>
</tr>
<tr>
<td>mtn3</td>
<td>2004</td>
<td>160:1</td>
<td>4.58</td>
<td>13.3</td>
</tr>
</tbody>
</table>
**TIN+Greedy Elevation Accuracy**

Compressed Size vs. Error

% RMS Elevation Error/Range

- Hill 1
- Hill 2
- Hill 3
- Mtn 1
- Mtn 2
- Mtn 3

**TIN+Greedy Slope Accuracy**

Compressed Size vs. Error

RMS Slope Error (degrees)

- Hill 1
- Hill 2
- Hill 3
- Mtn 1
- Mtn 2
- Mtn 3
Different Point Selection Strategies

- Previous slides: TIN+greedy.
- Allows progressive transmission of the points, (if replace bitmap coding of the $(X,Y)$ with a bzip2 compression).
- Following slides: regular grid point selection.
- Compresses better, but no progressive transmission.

- Marcus Andrade

Regular Grid ODETLAP Results

<table>
<thead>
<tr>
<th>Dataset</th>
<th># Points</th>
<th>Compressed Size</th>
<th>Compression Ratio</th>
<th>Elev RMS (m)</th>
<th>Slope RMS (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hill1</td>
<td>529</td>
<td>306</td>
<td>1046:1</td>
<td>9.63</td>
<td>4.32</td>
</tr>
<tr>
<td>Hill2</td>
<td>1600</td>
<td>807</td>
<td>397:1</td>
<td>9.98</td>
<td>6.54</td>
</tr>
<tr>
<td>Hill3</td>
<td>225</td>
<td>172</td>
<td>1860:1</td>
<td>9.71</td>
<td>3.04</td>
</tr>
<tr>
<td>Mtn1</td>
<td>4489</td>
<td>2194</td>
<td>146:1</td>
<td>9.66</td>
<td>10.13</td>
</tr>
<tr>
<td>Mtn2</td>
<td>4489</td>
<td>2027</td>
<td>158:1</td>
<td>9.95</td>
<td>10.34</td>
</tr>
<tr>
<td>Mtn3</td>
<td>4489</td>
<td>2013</td>
<td>159:1</td>
<td>9.91</td>
<td>9.85</td>
</tr>
</tbody>
</table>

(Our second ODETLAP point insertion strategy)
**Regular Grid ODETLAP Accuracy**

Compressed Size vs. Error

- Hill 1
- Hill 2
- Hill 3
- Mtn 1
- Mtn 2
- Mtn 3

% RMS Elevation Error/Range

**Missing Data Fillin**

ODETLAP  
Laplacian  
Thin plate

Matlab nearest  
Matlab linear  
Matlab cubic

Metin Inanc

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**Goal 2: Smugglers and Border Guards (aka Siting & Path Planning)**

- **Terrain**
- **Parameters:**
  - Observer height
  - Target height
  - Radius of interest
  - Intervisibility?
- **Siting program**
- **Observer positions**
- **Joint viewshed**

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**Multiobserver siting steps**

1. Compute approximate visibility index of every possible observer.
2. Compute exact viewsheds of the best.
3. Greedily insert potential observers into the final set of observers, maintaining a bitmap of the cumulative viewshed.
4. *Intervisibility:* insert only visible observers.

**Key:** fast bitmap operations allow hundreds of observers to be sited with hi-res viewsheds.
Sample Viewsheds

Note the level of detail

Siting Toolkit by ESRI

- **ArcGIS DLL toolkit**: an operational class configurable to perform siting simulations on any platform with a C++ compiler.
- Includes an ArcMap command application on Windows, to demonstrate its capabilities.
- Both are functional and scalable.
- Marquee Tool:

![Marquee Tool Image]

RPI / Geo* / ACM-GIS - Nov 8 2007
**ArcGIS DLL Dialog Box**

**Path Planning (Smugglers)**

- Find cheapest path between source and goal.
- Cost metric is not simply path length:

\[
\begin{align*}
  c &= \sqrt{\Delta x^2 + \Delta y^2 + \Delta z^2} \\
  &\quad \cdot \left(1 + \max \left(0, \frac{\Delta z}{\sqrt{\Delta x^2 + \Delta y^2}}\right)\right) \\
  &\quad \cdot (1 + 100v)
\end{align*}
\]

\((Distance)\)  
\((Climbing costs)\)  
\((BIG penalty for being seen)\)
Path planning algorithm

- Designed for hi-res, say 1000x1000, maps.
- Impossible to form the $10^6 \times 10^6$ cost matrix.
- Use A* to search for initial feasible, good, path.
- Iterate to optimize it.
- Doesn’t hang up on local optima.
- Compute many paths to evaluate compression throughout the terrain.
- Note how complex our paths are.

*Video:* multipath.wmv

- Dan

Many Paths on Each Dataset

hills1, hills2, hills3

mountains1, mountains2, mountains3
**Smugglers Path Evaluation of ODETLAP**

- **Size**: size of compressed dataset in bytes. *Original binary size=320KB.*
- **Incr. cost**: extra cost of optimal path computed on compressed dataset and evaluated on original dataset compared to optimal path computed on original dataset.

<table>
<thead>
<tr>
<th>Data</th>
<th>Size</th>
<th>Compr. Ratio</th>
<th>Incr. Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>hill1</td>
<td>1763</td>
<td>182:1</td>
<td>5.5%</td>
</tr>
<tr>
<td>hill2</td>
<td>1819</td>
<td>176:1</td>
<td>6.1%</td>
</tr>
<tr>
<td>hill3</td>
<td>1607</td>
<td>199:1</td>
<td>4.4%</td>
</tr>
<tr>
<td>mtn1</td>
<td>1925</td>
<td>166:1</td>
<td>19.2%</td>
</tr>
<tr>
<td>mtn2</td>
<td>1884</td>
<td>170:1</td>
<td>18.2%</td>
</tr>
<tr>
<td>mtn3</td>
<td>1946</td>
<td>164:1</td>
<td>17.0%</td>
</tr>
</tbody>
</table>

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**Path Planning for Road Construction**

- **Goal**: Construct an optimal road connecting two points.
- **Allowed**: Material removal and deposition.
- **Constraint**: Max allowable slope is bounded.
- **Objective function**: Amount of material moved.
- **Method**: A*
Before merging

After merging

Larger more realistic watersheds and drainage networks, feed points into ODETLAP

- Jon Mucke

Future - Scooping

- Terrain not continuous.
- *Thesis*: methods (Fourier, ODETLAP, ...) assuming that are wrong.
- Model terrain as sequence of terraforming operators.
  - Water erosion
- Implement descriptive geography
- Easy to say, hard to do.
**Team**

- Prof Randolph Franklin – helping everyone
- Prof Barbara Cutler – computer graphics
- Prof Frank Luk (*on leave as Vice-President (Academic) of Hong Kong Baptist U*) – numerical analysis
- Prof Marcus Andrade – visiting from UF Viçosa (Brazil) – computational geometry
- Metin Inanc – ODETLAP
- Zhongyi Xie – ODETLAP
- Dan Tracy – multiobserver siting, path planning
- Jon Muckell – hydrology.
- NSF, DARPA – financial support, direction.

**Summary**

- Represent terrain in 1% of original binary space with compression ratios of 80:1 to 500:1 with 10m elevation and 5-10 degree slope error.
- Site border guards, plot smugglers paths.

**Future**

- Scooping.
- Hydrology.
- Better slope representation.
- Large urban datasets.